The System of Rice Intensification (SRI): Revisiting Agronomy for a Changing Climate

Photo: E. Styger

Overview of practice

By modifying management of rice plants, soil, water and nutrients to improve growth environments, farmers can get higher-yielding, more vigorous and resilient plants nurtured by larger root systems and greater diversity/abundance of beneficial soil organisms. More productive phenotypes from available genotypes enhance farmers' income and security while reducing their costs and water requirements.

GLOBAL ALLIANCE FOR CLIMATE-SMART AGRICULTURE

Erika Styger and Norman Uphoff

KEY MESSAGES

1. SRI methodology for rice production contributes to all three pillars of CSA.
2. SRI proceeds from a set of agronomic principles that enable farmers to adapt their production practices more beneficially to their local environments.
3. SRI methodology aims at eliciting the full expression of each individual plant's genetic potentials.
4. SRI is creating CSA impacts in a wide range of eco-zones and rice production systems in over 50 countries. SRI is also successfully adapted to other crops.

SRI-RICE
SRI INTERNATIONAL NETWORK AND RESOURCES CENTER

The System of Rice Intensification (SRI) as a knowledge-based methodology increases the productivity and resilience of rice, and more recently also of other crops. Its simple changes of agronomic practices were assembled in close collaboration with farmers during the 1970s-80s in Madagascar. Since 2000, SRI has been spreading to other countries, and today we estimate that more than 10 million farmers are benefiting from the application of this methodology in more than 50 countries of Asia, Africa and Latin America (SRI-Rice 2016a; FAO 2016; World Bank 2010). Conceptually and operationally, SRI is based on the following principles that provide an adaptive foundation for its practice:

1. Encourage early and healthy plant establishment;
2. Minimize competition among plants;
3. Build up fertile soils that are well-endowed with organic matter and beneficial soil biota; and
4. Manage water to avoid both flooding and water stress (SRI-Rice 2016b)

These **principles** remain the same wherever farmers are growing rice or other crops when following the System of Crop Intensification (SCI). Their application in specific practices can and should vary according to local conditions, e.g., modifying spacing distance in response to different levels of soil fertility.

Common SRI **practices** for growing irrigated rice, for which SRI was initially developed, include (SRI-Rice 2016b):

- Separate viable from non-viable seeds by soaking them in salt water or plain water; this also speeds up germination process (principle 1);
- Sow seeds non-densely on a raised-bed, unflooded nursery with well-structured, well-drained and fertile soil (principles 1, 2, 3, 4);
- Transplant single young seedlings at the 2-leaf stage, usually between 8-12 days old, in a grid pattern with wide spacing between hills; 25 cm x 25 cm is usually a good distance to start with (principles 1, 2);
- Follow alternate wetting and drying irrigation methods during the period of vegetative growth, and avoid deep flooding thereafter (principle 4);
- Apply composted organic matter as base fertilization, and complement this with mineral fertilizer as needed (principle 3).
- Control weeds with a mechanical weeder that incorporates them into the soil and also enhances soil aeration (principles 2, 3, 4).

SRI practices have been adapted successfully for **rainfed rice** production, (Sinha and Talati 2007; Kabir and Uphoff 2007), either by transplanting seedlings timed with the onset of rains or by direct-seeding of 2 seeds per hill. Location-specific water management practices for rainfed SRI include, among others, bunding of plot boundaries, mulching of the field to conserve moisture, or making changes in the cropping calendar to avoid heavy rains and deep flooding during the vegetative growth period of lowland rice. The other SRI practices developed for irrigated rice can be adapted also with rainfed rice, e.g., organic fertilization of soil, wider spacing, and use of a soil-aerating weeder. SRI farmers have begun adapting SRI practices also to **other crops**, as noted below.

Benefits of SRI

Crop productivity increases: The combined changes in crop management result in plant phenotypes which give greater crop yields and have more resilience to stresses. Rice yields are improved by 20-50%, and often by more (Uphoff 2012). Better grain quality often earns a higher market price; and when the rice is organically grown, its price can be even higher.

A farmer from Vietnam's Ha Noi Province shows a SRI rice plant and field shown on left, and conventional plant and field on right, (same variety), after a tropical storm has passed. Photo: E. van de Fliert

Increased income: Whether production costs and labour requirements for SRI methods are higher, equal or lower than in conventional rice production will depend on what is the current practice, the degree of intensification, and the types of changes needed to move to SRI practices (Thakur et al. 2013). Significantly higher yields increase, both labour and input factor productivity with SRI, raising farmers' income from rice in most cases by 50% or more with SRI adoption, and with all three of the scenarios noted above (Thakur et al. 2013; Kathikeyan et al. 2010; Uphoff 2016).

One single plant grown with the SRI method showing a very large root system and over 50 tillers, in Douegoussou village of Timbuktu region of Mali. Photo: H. Guindo

Applicable with any variety: SRI methods have resulted in increased crop productivity for hybrids, high-yielding varieties, local, and indigenous varieties (Uzzaman et al. 2015). SRI methods are ideal for seed production, since with higher yield and reduced seed requirements, the seed multiplication rate can exceed 1000x with SRI, compared to 90-100x with standard methods (Styger 2013).

Greater resilience: SRI rice fields can maintain productivity under unfavourable conditions, including climate variations, drought, storms, pest and disease pressure (see section on Adaptation).

Challenges for adoption of SRI

Quality of training and technical follow-up: For best results, farmers need to understand the SRI methodology well and gain confidence in it. This is best done over at least three rice cropping seasons. In the first season, farmers witness the crop performance improvements through demonstrations, preferably on their own fields. In the second season they confirm the experience and gain technical proficiency; and in the third season they start expanding surface area and integrating SRI into their broader farming systems and community-based activities, such as irrigation management and mobilization of labour.

It is advisable that some technical support be provided beyond 3 years as farmers need to integrate the newly-gained knowledge with their other farming and non-farming activities (Styger et al. 2011).

Importance of rice production to households and their opportunity costs: If rice is farmers' primary crop and already intensively-cultivated, and if getting the greatest returns from their land and other resources is desired, SRI will be very attractive. Where rice is cultivated in a more extensive manner or as a secondary crop with substantial opportunity costs of intensification, SRI will be of less interest to these farmers.

Farmers interested in intensifying their production need access to the necessary production factors including labour. Most farmers aspire to and benefit from raising the productivity of their land, labour, water, seed and capital inputs. Farmer interest in SRI is often driven by a desire to cut back on the volume of water, seeds and agro-chemical inputs that they require, reducing production costs while achieving higher crop productivity and achieving more crop resilience against climatic and other stresses.

Access to appropriate tools and equipment: Access to suitable weeders, transplanters or direct-seeders for SRI operations is often lacking. Many weeder prototypes have been developed for varying environments, but their distribution remains a challenge within some countries. Mechanical transplanters and direct-seeders that perform well for SRI are still being developed in some places. If implements are not available, this slows SRI adoption for labour-constrained households or for medium- and larger-scale farming operations.

Assuring market access: Increases in overall rice production need to be accompanied by improved market access and appropriate remuneration for the crop produced, even when farmers are growing rice just as their staple food. If market payoff is not assured, farmers are less likely to be interested in increasing their production and in crop intensification.

Policy support: This is crucial since SRI like other agro-ecological approaches works within a longer-term time frame. Government subsidization of agrochemical inputs, for instance, can divert farmers' efforts and interests away from making sustainable intensification efforts.

Social organization of labour and of water management: Farmers do not cultivate in isolation. They are embedded in communities where agricultural operations are to some extent synchronized and cooperative. In order to change rice production practices and go to scale, a social process of embracing this change needs to happen, especially in irrigation schemes where farmers depend on each other for water access and management (Styger et al. 2011).

Learning process involving successful farmers: In most countries, farmers have given leadership in the development and adaptation of SRI practices. Extension services, often oriented toward input-based technologies, need to be well-trained on the SRI principles and practices in order to be effective in their job. At present, most research is undertaken through on-station experiments rather than in farmers' fields.

Unless this research model is superseded, with farmers actively engaged in developing and optimizing agronomic practices -- participating in a 'triangular' rather than a 'linear' model for R&D (Merrill-Sands and Kaimowitz 1990) -- much of the potential for development of further innovations and for mutual learning with SRI will be forgone.

Where can SRI be practiced?

SRI methods are being successfully used in all the main rice-growing climates around the world (SRI-Rice 2016a) and in both irrigated as well as rainfed rice systems.

Factorial trials have shown that best results are achieved when crop production practices are consistent with all of the SRI principles (Uphoff and Randriamiharisoa 2002). In irrigated systems, for instance, it is best to have plot-level control of irrigation water. However, farmers often use SRI methodology in less than optimal conditions. If not able to follow all principles well, farmers can still obtain benefits from partial implementation as seen from a study of >2300 SRI farmers across 13 states of India (Palanisami et al. 2013).

Maturing SRI fields in Gonaive, Haiti.Photo: E. Styger

Refinements and adjustments of practices are continually needed. Farmers constantly seek to optimize their practices, especially in view of climate change (Sen 2015). Priority should therefore be given to detailed reporting and assessment of practices in different environments to identify locally adapted practices. Research needs to focus on observations made of farmers' field performances. Learning efficiently and cumulatively from what works for farmers, and what types of innovations can best address their constraints, should be a priority.

SRI farmers have begun applying SRI principles to other crops, such as wheat, sugarcane, finger millet, teff, mustard and various legumes and vegetables (Abraham et al. 2014; Behera et al. 2013). This has been primarily a farmer-driven process, with some NGO and research involvement. The benefits of this extrapolation are starting to be documented, e.g., for wheat in India (Dhar et al. 2016) and tef in Ethiopia (Agricultural Transformation Authority 2015)

SRI methodology has been taken up in a number of conflict and post-conflict areas such as in Iraq, Afghanistan, Sri Lanka, Sierra Leone and Northern Mali (SRI-Rice 2016a), enabling local populations to produce their staple food when cut off from access to outside inputs. This is also true for post-disaster areas as when SRI was introduced in Aceh, Indonesia to rebuild food production systems after the 2004 *tsunami* there (Cook and O'Connor 2009). Some disaster-preparedness programs are now integrating SRI into their efforts to reduce communities' vulnerability to storm damage and drought (ADRA 2014; CARITAS 2015).

Contribution to CSA pillars

How SRI increases productivity, farm livelihoods and food security

The combined application of the SRI practices results in **improved plant phenotypes and physiological processes**. SRI plants grow taller, have stronger and thicker tillers, thicker leaves, deeper roots, and a much larger root mass in combination with improved photosynthesis efficiency (Thakur et al. 2010; Mishra and Salokhe 2010; Gopalakrishnan et al. 2013). Also, increases in beneficial microbial activity and processes have been recorded in the SRI plant-soil environment, which are key for improved plant performance and productivity (Anas et al. 2011; Zhao et al. 2009; Lin et al. 2011).

Farm livelihood and food security are improved based on significantly higher yields, usually associated with similar or lower cost of production compared to conventional methods. This results in increased income and the availability of more rice at household level.

Many SRI farmers in Asia and Africa achieve rice self-sufficiency and even produce a surplus, which allows them to sell some rice and cover household costs such as medical expenses and school fees for their children, among others. Another strategy to take advantage of SRI's higher productivity is to reduce the land area under rice and to diversify into higher-value products such as horticulture and/or aqua-culture (Lim 2007; Thakur et al. 2016). This

Adjacent paddy fields in East Java, Indonesia after both had been subjected to a brown plant hopper attack followed by a tropical storm. The field on left, planted with a modern variety (Ciherang) and supported with modern inputs, experienced hopper damage (burn) and lodging, resulting in little yield. The field on right, planted with a traditional aromatic variety (Sinantur) and grown with SRI methods including organic fertilization, tolerated these biotic and abiotic stresses and produced 800 kg from 1000 m^2, a yield of 8 tons per hectare. Photo: M. Jannah.

diversifies household food supply for better family nutrition.

SRI field where alternate wetting and drying is well-applied showing fast development of young plants under harsh climatic conditions. Photo: E. Styger

How SRI helps farmers adapt to and increase their resilience to the impacts of climate change

Based on the improved and stronger plant types with larger and deeper root systems that result from applying SRI methods, these plants are more resilient toward climate-change impacts as witnessed every year in the countries where farmers have adopted SRI. Among the most important benefits are:

Reduced water requirements and greater drought resistance: SRI plants thrive with 30-50% less irrigation water compared to always-flooded rice. Reduced competition among plants in combination with aerated and organic matter-enriched soils creates stronger plants above and below ground with larger, deeper, less-senescing root systems, which can resist drought and extreme temperatures better. Also, organic matter-enriched soils are able to store more water as well as nutrients (Jagannath et al. 2013; Zheng et al. 2013; Barison and Uphoff 2011; Sridevi and Chellamuthu 2012; Chapagain et al. 2011; FAO 2005).

Higher pest and disease resistance: Stronger and healthier rice plants are less susceptible to pest and disease attacks. Given the much lower plant density with SRI, less humidity builds up within the plant canopy as air can circulate more easily among the plants. This provides pest and diseases with a less favorable environment compared to densely-planted and continually-flooded conventional rice paddies (Karthikeyan et al. 2010; Kumar et al. 2007; Visalakshmi et al. 2014).

Greater resistance to rain and wind damage from storms. As SRI plants have thicker tillers and deeper roots, and as they are more widely spaced, they have been shown to resist strong rain and winds better than conventional paddy rice. A study in Japan reported that during a storm event, 10% of SRI field lodged compared to 55% of an adjacent conventionally-managed field (Chapagain et al. 2011 -- see picture from Vietnam on page 2).

How SRI mitigates greenhouse gas emissions

SRI management contributes to mitigation objectives by decreasing the emissions of greenhouse gases (GHG) when continuous flooding of paddy soils is stopped and other rice-growing practices are changed.

- Methane (CH_4) is reduced between 22% and 64% as intermittent irrigation (or alternate wetting and drying, AWD) means that soils have more time under aerobic conditions (Gathorne-Hardy et al. 2013, 2016; Choi et al. 2015; Jain et al. 2014; Suryavanshi et al. 2013; Wang 2006; Dill et al. 2013).
- Nitrous oxide (N_2O) emissions increase only slightly with SRI or sometimes decrease as the use of N fertilizers is reduced. No studies so far have shown N_2O increases offsetting the gains from CH_4 reduction (Kumar et al. 2007; Visalakshmi et al. 2014; Vermeulen et al. 2012; Gathorne-Hardy et al. 2013, 2016; Choi et al. 2015).
- Total global warming potential (GWP) from rice paddies was reduced with SRI methods in the above studies by 20-30%, and up to 73% in one of the studies (Choi et al. 2015).
- Rice production's carbon footprint is reduced to the extent that less fertilizer and fewer agrochemicals are used. GHG emissions from producing, distributing and using these inputs equal about 5-10% of the global warming potential (GWP) from all direct emissions from food production (Vermeulen et al. 2012).

GHG emission studies with SRI are still in the early stages, and more detailed studies are needed to better link and understand how individual practices contribute to increasing or reducing GHG emissions. However, the mitigation potential of alternate wetting and drying, a component of SRI, is well established (Richards and Sander 2014).

Costs and funding for SRI

Costs for introducing SRI to new locations, for testing and adapting the practices, are mostly related to extension activity and knowledge-sharing, data-collection, and reporting on results. Good training of extension staff is essential, as SRI is knowledge-based. Well-trained and motivated extension staff makes a huge difference in impact when working with farmers. Staff should focus on experimenting and learning together with farmers.

Farmers play an important role in many countries in the dissemination of SRI knowledge and practice, all without much associated external funding. At the farmer level, input costs are usually reduced as already explained. (Palanisami et al. 2013). The only recommended purchase for SRI is a simple mechanical weeder whose one-time cost can be recouped several times over within the first season.

Program funding for SRI training and technical support has lagged far behind the demands from farmers in Asia, Africa and Latin America. Most SRI initiatives have started directly with farmers at the local level and have proceeded with very little support. Based on local successes, SRI has expanded in most countries to national or sub-national levels through funding from governments, multi-lateral or bi-lateral donors and NGOs where SRI was integrated into on-going agriculture projects.

More recently larger-scale, regional SRI projects have been initiated with funding through the World Bank in West Africa (http://sriwestafrica.org) and through the European Union in Southeast Asia (http://www.sri-lmb.ait.asia). For scaling up, the time is right to reinforce and increase regional SRI initiatives. With adequate support, the authors estimate that it would be easily possible to reach and benefit 30-50 million or more farmers in the next 10 years.

Ibrahim Hamidou, from the village of Hara Hara, region of Timbuktu in Mali, is using a mechanical weeder in his SRI field, which besides weed control also contributes to soil aeration; plot leveling and stimulating nutrient uptake by plants from previously incorporated manure. Photo: E. Styger

Metrics for CSA performance of SRI

- Agronomic and economic measurements reflecting **productivity**, the first pillar of CSA, are standard ones: measuring yield in combination with details on practices, and cost/benefit analysis comparing SRI results with current/common practices. Monitoring the number of farmers and area under SRI over time is important to understand the dynamics and conditions of adoption and adaptation of SRI as an innovation.
- Assessing the second pillar, **adaptation**, can be done by undertaking yield comparisons between SRI and conventional plots -- with associated economic evaluation -- under different biotic and abiotic stresses such as drought, flooding, storm damage, stressful temperatures, and pests and diseases.
- To evaluate the third pillar, **mitigation**, technical measurements should be made for increases or decreases in CH_4 and N_2O emissions from rice fields comparing fields planted with SRI and current methods under typical and under stressed climatic conditions (Butterbach-Bahl et al. n.d.)

First rice farmers in Rio Grande do Sul state of Brazil to use SRI methods, with a doubling of their yield. Photo: A. Gonçalves

Interaction with other CSA practices

Climate-smart agricultural practices need to be developed, integrated and evaluated within a larger farming-systems and landscape-ecology approach. A good start is assist convergence of agroecological approaches such as SRI, conservation agriculture, agroforestry, integrated pest management, integration of livestock systems, and aquaculture, with climate-resilient crop production, and organic farming.

Particular attention should be paid to increasing and maintaining above and below-ground carbon stocks as well as sustaining plant, animal and microbial biodiversity, in addition to reinforcing symbiotic relationships that improve the efficiency of nutrient, water and carbon cycles.

Conservation agriculture and SRI have been combined in zero-till raised-bed rice production systems in China or Pakistan (Sharif 2011; Lu et al. 2013). Another systems approach, the Saguna Rice Technique (SRT) (Saguna Rice Technique 2014) developed in India combines conservation agriculture, organic farming, and SRI/SCI crop management practices.

SRI includes alternate wetting and drying (AWD), another CSA practice, one of its component practices. (Richards and Sander 2014).

An example of agroforestry and SRI integration is the direct use of nitrogen-rich biomass produced through the leguminous agroforestry species *Gliricidia sepium*, planted on rice paddy field bunds. This enables farmers to benefit from a previously unused landscape niche, sequestering more carbon, and providing organic matter on-location as shrub branches can be cut and directly used to add plant nutrients to the fields during their preparation.

There are many opportunities to further integrate available agroecological approaches with each other and adapt to local conditions by studying what is already practiced and researched.

Setting up a successful SRI initiative

- **Be flexible:** While the **principles** of SRI remain the same, the **practices** applying them should always be adapted to local and to farm conditions. While the full set of recommended SRI practices usually give best results, moving to SRI crop management can be done in incremental steps provided that the principle of maintaining mostly aerobic soil conditions is respected. These directly affect the health and growth of plant roots and the soil biota.
- **Be concrete and visual:** SRI is an empirical innovation, and farmers should be able to see for themselves the yield and resilience gains. If they start with only some of the recommended practices, demonstrations with the full set of practices should also be set up somewhere as well, so that farmers can observe and understand the positive interactions of applying all the practices together and can see their joint impact on productivity and resilience.
- **Gather and present data on agronomic, economic and environmental benefits:** As long as innovations that have been adapted and are working well in farmers' fields are not well-documented and shared, they remain invisible to the agricultural R&D community as well as to policy and decision-makers.
- **Recording economic as well as agronomic data** is important since farmers need to know about profitability. Data on water consumption and resilience to various climate-related stresses should also be systematically gathered and assessed, documenting season-to-season differences.
- **Develop appropriate mechanization:** In some farming systems, SRI practices will be relatively more labour-intensive to start out, and elsewhere they will need to be labour-saving. Farmers in most countries face ever-greater constraints from labour cost and availability. Thus the development of suitable implements and equipment is important (Sharif 2011)**,** especially for SRI adaptation in larger-scale farming.
- **Integrate SRI methodology into farming systems approaches** by combining SRI with other climate-smart and agro-ecological strategies, and also by applying SRI principles to other crops such as wheat and finger millet (Abraham et al. 2014; Behera et al. 2013; Dhar et al. 2016).
- **Maintain farmer leadership:** SRI progress and improvement has been driven in large part by farmer initiative and innovation. Farmer-to-farmer spread of the new ideas and practices is important, with extension systems working in more farmer-centered ways. SRI has not been and should not become a top-down and rigid methodology, as *adaptation* is more important than *adoption*. This should be a guiding principle for improving and advancing most if not all climate-smart agriculture.

Organic Jasmine rice planted with SRI methods and harvested in Cambodia by Py Phal, farmer from Prasat village, Takeo Province; Photo: E. Styger

Sources and further reading

Abraham B, Araya H, Berhe T, Edwards S, Gujja B, Khadka RB, Koma YS, Sen D, Sharif A, Styger E, Uphoff N, Verma A. 2014. The System of Crop Intensification: Reports from the field on improving agricultural production, food security and reliance to climate change for multiple crops. *Agriculture & Food Security* 3:4.

ADRA. 2014. Saving lives through disaster resistance. *Muling Ibalik Quarterly Newsletter* No.4. Available from: http://reliefweb.int/sites/reliefweb.int/files/resources/ADRA%20Newsletter%20Q4%202014.pdf

Agricultural Transformation Authority. 2015. *Annual Report: Transforming Agriculture in Ethiopia, 2013/2014.* Addis Ababa, Ethiopia: ATA.

Anas I, Rupela OP, Thiyagarajan TM, Uphoff N. 2011. A review of studies on SRI effects on beneficial organisms in rice soil rhizospheres. *Paddy & Water Environment* 9: 53-64.

Barison J, Uphoff N. 2011. Rice yield and its relation to root growth and nutrient use efficiency under SRI and conventional cultivation: An evaluation in Madagascar. *Paddy & Water Environment* 11: 65-75.

Behera D, Chaudhary AK, Vutukuru VK, Gupta A, Machiraju S, Shah P. 2013. *Enhancing Agricultural Livelihoods through Community Institutions in Bihar*. World Bank, New Delhi.

Butterbach-Bahl K, Sander BO, Pelster D, Diaz-Pines E. Not Dated. Quantifying greenhouse gas emissions from managed and natural soils. *SAMPLES Project*, Chapter 4. CCAFS. Available from: http://samples.ccafs.cgiar.org/measurement-methods/chapter-4-quantifying-greenhouse-gas-emissions-from-managed-and-natural-soils

CARITAS. 2015. Harvest in the Philippines. Available from: http://svet.charita.cz/en/where-we-help/asia/philippines/photos-from-philippines/harvest-in-the-philippines/

Chapagain T, Riseman A, Yamaji E. 2011. Assessment of System of Rice Intensification (SRI) and conventional practices under organic and inorganic management in Japan. *Rice Science* 18: 311-320.

Choi J, Kim G, Park W, Shin M, Choi Y, Lee S, Lee D, Yun D. 2015. Effect of SRI methods on water use, NPS pollution discharge, and greenhouse gas emissions in Korean trials. *Paddy & Water Environment* 13: 205-213.

Cook G, O'Connor T. 2009. Rice aplenty in Aceh. *Caritas News, Spring* 9-11.

Dhar S, Barah BC, Vyas AK, Uphoff N. 2016. Comparing System of Wheat Intensification (SWI) with standard recommended practices in the northwest plain zone of India. *Archives of Agronomy & Soil Science* 62(7).

Dill J, Deichert G, Le TNT. 2013. *Promoting the System of Rice Intensification: Lessons Learned from Trà Vinh Province*, Vietnam, GIZ and IFAD, Hanoi. Available from: http://infoagro.net/archivos_Infoagro/Regatta/biblioteca/VN-GIZreportonLesson.pdf

FAO. 2005. *Creating Drought-Resistant Soil*. Available from: http://www.fao.org/docrep/009/a0100e/a0100e08.htm

FAO. 2016. *Save and Grow: Maize, Rice and Wheat – A Guide to Sustainable Crop Production.* UN Food and Agriculture Organization, Rome: 44-47.

Gathorne-Hardy A, Reddy DN, Venkatanarayana M, Harriss-White B. 2013. A Life Cycle Assessment (LCA) of greenhouse gas emissions from SRI and flooded rice production in SE India. *Taiwan Water Conservancy* 61: 110-12.

Gathorne-Hardy A, Reddy DN, Venkatanarayana M, Harriss-White B. 2016. System of Rice Intensification provides environmental and economic gains at the expense of social sustainability: A multi-disciplinary analysis in India. *Agricultural Systems* 143: 159-168.

Gopalakrishnan S, Kumar RM, Humayun P, Srinivas V, Ratna Kumari B, Vijayabharathi R, Singh A, Surekha K, Padmavathi C, Somashekar N, Raghuveer Rao P, Latha PC, Subba Rao LV, Babu VR, Viraktamath BC, Vinod Goud V, Loganandhan N, Gujja B, Rupela O. 2013. Assessment of different methods of rice (Oryza sativa. L) cultivation affecting growth parameters, soil chemical, biological and microbiological properties, water saving and grain yield in rice–rice system. *Paddy & Water Environment* 12: 79-87.

Jagannath P, Pullabhotla H, Uphoff N. 2013. Meta-analysis evaluating water use, water saving and water productivity in irrigated production of rice with SRI vs. standard management methods. *Taiwan Water Conservancy* 61: 14-49.

Jain N, Dubey R, Dubey DS, Singh J, Khanna M, Pathak H, Bhatia A. 2014. Mitigation of greenhouse gas emissions with system of rice intensification in the Indo-Gangetic plains. *Paddy & Water Environment* 12: 355-363.

Kabir H, Uphoff N. 2007. Results of disseminating the System of Rice Intensification (SRI) with farmer field school methods in northern Myanmar. *Experimental Agriculture* 43: 463-476.

Karthikeyan K, Sosamma J, Purushothaman SM. 2010. Incidence of insect pests and natural enemies under SRI method of cultivation. *Oryza* 47: 154-157.

Kumar, RM, Padmavathi C, Surekha K, Latha PC, Krishnamurthy P, Singh SP. 2007. Influence of organic nutrient sources on insect pests and economics of rice production in India. *Indian Journal of Plant Protection* 35: 264-267.

Lim S. 2007. *Experiences in Multi-Purpose Farm Development: Raising Household Incomes in Cambodia by Utilizing Productivity Gains from the System of Rice Intensification*. Phnom Penh, Cambodia: Cambodian Center for Study and Development of Agriculture (CEDAC). Available from: http://sri.ciifad.cornell.edu/countries/cambodia/ cambSidMPREng.pdf

Lin X, Zhu D, Lin X. 2011. Effects of water management and organic fertilization with SRI crop practices on hybrid rice performance and rhizosphere dynamics. *Paddy & Water Environment* 9: 33-39.

Lu SH, Dong YJ, Yuan J, Padilla H. 2013. A high-yielding, water-saving innovation combining SRI with plastic cover on no-till raised beds in Sichuan, China. *Taiwan Water Conservancy* 61: 94-109.

Merrill-Sands D, Kaimowitz D. 1990. *The Technology Triangle*. The Hague, Netherlands: ISNAR.

Mishra A, Salokhe VM. 2010. The effects of planting pattern and water regime on root morphology, physiology and grain yield of rice*. Journal of Agronomy & Crop Science* 196: 368-378.

Palanisami K, Karunakaran KR, Amarasignhe U, Ranganathan CR. 2013. Doing different things or doing it differently? Rice intensification practices in 13 states of India. *Economic & Political Weekly* 48: 51-58.

Richards M, Sander BO. 2014. Alternate wetting and drying in irrigated rice: Implementation guidance for policymakers and investors. *Practice Brief, Climate-Smart Agriculture*. Climate Change, Agriculture and Food Security (CCAFS). Available from: https://cgspace.cgiar.org/rest/bitstreams/34363/retrieve

Saguna Rice Technique. 2014. Available from: https://sagunarice.wordpress.com/

Sen D. 2015. How Smallholder Farmers in Uttarakhand Reworked the System of Rice Intensification: Innovations from Socio-Technical Interactions in Fields and Villages. PhD dissertation, Wageningen University.

Sinha SK, Talati J. 2007. The impact of system of rice intensification (SRI) on paddy productivity: Results of a study in Purulia District, West Bengal, India. *Agricultural Water Management* 87: 55-60.

Sharif A. 2011. Technical adaptations for mechanized SRI production to achieve water saving and increased profitability in Punjab, Pakistan. *Paddy & Water Environment* 9: 111-119.

Sridevi V, Chellamuthu V. 2012. Advantages of SRI cultivation in the tail end of Cauvery Delta. *Journal of Crop & Weed* 8: 40-44.

SRI-Rice. 2014. *The System of Crop Intensification: Agroecological Innovations for Improving Agricultural Production, Food Security, and Resilience to Climate Change.* SRI-Rice, Cornell University, Ithaca, New York, and Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, Netherlands. Available from: http://publications.cta.int/en/publications/publication/1795/management-entrepreneurship/

SRI-Rice. 2016a. Countries. Available from: http://sri.cals.cornell.edu/countries

SRI-Rice. 2016b. SRI methodologies. Available from: http://sri.cals.cornell.edu/aboutsri/methods/index.html

Styger E, Aboubacrine G, Ag Attaher M, Uphoff N. 2011. The system of rice intensification as a sustainable agricultural innovation: introducing adapting and scaling up system of rice intensification practices in the Timbuktu region of Mali. *International Journal of Agricultural Sustainability* 9: 67-75.

Styger E. 2013. The System of Rice Intensification (SRI): How a crop management approach lets farmers preserve and improve productivity of indigenous rice varieties in Asia and Africa. Presentation at the Carolina Gold Rice Foundation Annual Meeting, Charleston, South Carolina.

Suryavanshi P, Singh YV, Prasanna R, Bhatia A, Shivay YS. 2012. Pattern of methane emission and water productivity under different methods of rice crop establishment. *Paddy & Water Environment* 11: 321-32.

Thakur AK, Mohanty RK, Singh R, Patil DU. 2015. Enhancing water and cropping productivity through Integrated System of Rice Intensification (ISRI) with aquaculture and horticulture under rainfed conditions. *Agricultural Water Management* 161: 65-76.

Thakur AK, Rath S, Mandal KG. 2013. Differential responses of system of rice intensification (SRI) and flooded-rice management methods to applications of nitrogen fertilizer. *Plant & Soil* 370: 59-71.

Thakur AK, Uphoff N, Antony E. 2010. An assessment of physiological effects of System of Rice Intensification (SRI) compared with recommended practices in India. *Experimental Agriculture* 46: 77-98.

Thakur AK, Uphoff N, Stoop W. 2016. Scientific underpinnings of the System of Rice Intensification (SRI): What is known so far. *Advances in Agronomy* 135: 147-179.

Uphoff N. 2012. Supporting food security in the 21st century through resource-conserving increases in agricultural production. *Agriculture & Food Security* 1(18).

Uphoff N. 2016. Developments in the System of Rice Intensification. In: Sasaki T (ed.) *Achieving Sustainable Rice Production*. Cambridge, UK: Burleigh-Dodds.

Uphoff N, Randriamiharisoa R. 2002. Reducing water use in irrigated rice production with the Madagascar System of Rice Intensification. In: Bouman BAM, Hengsdijk H, Hardy B, Bindraban PS, Tuong TP, Ladha JK (eds.). *Water-Wise Rice Production.* Los Baños, Philippines, International Rice Research Institute: 71-86.

Uzzaman T, Sikder RK, Asif MI, Mehraj H, Jamal Uddin AFM. 2015. Growth and yield trial of sixteen rice varieties under System of Rice Intensification. *Scientia Agricolae* 11: 81-89.

Vermeulen SJ, Campbell BM, Ingram JSI. 2012. Climate change and food systems. *Annual Review of Environmental Resources* 37: 195-222.

Visalakshmi V, Rama Mohana Rao P, Hari Satyanarayana H. 2014. Impact of paddy cultivation systems on insect pest incidence. *Journal of Crop & Weed* 10: 139-142.

Wang Y. 2006. N_2O emission from paddy field under different rice planting modes. *Wuhan University Journal of Natural Sciences* 11: 989-996.

World Bank. 2010. World Bank Institute website page: http://info.worldbank.org/etools/docs/library/245848/

Zhao L, Wu L, Li Y, Zhu D, Uphoff N. 2009. Influence of the System of Rice Intensification on rice yield and on nitrogen and water use efficiency with different N application rates. *Experimental Agriculture* 45: 275-286.

Zhao L, Wu L, Li Y, Animesh S, Zhu D, Uphoff N. 2010. Comparisons of yield, water use efficiency, and soil microbial biomass as affected by the System of Rice Intensification. *Communications in Soil Science & Plant Analysis* 41: 1-12.

Zheng JG, Zhou L, Chi ZZ, Jiang XL. Agricultural water savings possible through SRI for water management in Sichuan, China. *Taiwan Water Conservancy* 61: 50-62.

PRACTICE BRIEFS ON CSA

The Practice Briefs intend to provide practical operational information on climate-smart agricultural practices.

Please visit http://www.fao.org/gacsa/ for more information.

Authors

Erika Styger, PhD, is Associate Director for the SRI International Network and Resources Center (SRI-Rice) at International Programs, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY (eds8@cornell.edu)

Norman Uphoff is Professor of Government and International Agriculture, and Senior Advisor to the SRI International Network and Resources Center, Cornell University, Ithaca, NY (ntu1@cornell.edu)

Disclaimer

Date published September 2016

Front cover photo: Youssouf Aboubacrine, from the village of Horogoungou, in the Timbuktu region of Mali, in his vigorously growing SRI field, which was planted with single 10 day old seedlings. Youssouf is able to save up to 50% of irrigation water and to increase rice yields from previously 4.5 t/ha to 8 t/ha. Photo by Erika Styger